



Project Summary

Demonstration of Fuel Cells to Recover Energy from Landfill Gas—Phase III. Demonstration Tests, and Phase IV. Guidelines and Recommendations

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The report summarizes the results of a four-phase program, conducted to demonstrate that fuel cell energy recovery using a commercial phosphoric acid fuel cell is both environmentally sound and commercially feasible. Phase I, a conceptual design and evaluation study, addressed the technical and economic issues associated with operation of the fuel cell energy recovery system of landfill gas (LFG). Phase II included the design, construction, and testing of a LFG pretreatment unit (GPU) to remove critical fuel poisons such as sulfur and halides from the LFG, and the design of fuel cell modifications to permit operation on low heating value (LHV) LFG. Phase III was the demonstration test of the complete fuel cell energy recovery system. Phase IV described how the commercial fuel cell power plant could be further modified to achieve full rated power on LHV LFG.

The demonstration test successfully demonstrated operation of the energy recovery system, including the GPU and the commercial phosphoric acid fuel cell modified for operation on LFG. Demonstration output included: operation up to 137 kW; 37.1% efficiency at 120 kW; exceptionally low secondary emissions (dry gas, 15% oxygen) of 0.77 ppmV carbon monoxide, 0.12 ppmV nitrogen oxides, and undetectable sulfur dioxide; no forced outages with adjusted availability of 98.5%; and 709 hours operation on LFG. The pretreatment (GPU) operated for 2,297 hours, including 709 hours with the fuel cell, and documented total sulfur and halide removal to much lower than

specified <3 ppmV for the fuel cell. The GPU flare safely disposed of the removed LFG contaminants by achieving destruction efficiencies >99%. An environmental and economic evaluation of a commercial fuel cell energy system concluded that there is a large potential market for fuel cells in this application.

This Project Summary was developed by the National Risk Management Research Laboratory's Air Pollution Prevention and Control Division, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The U.S. EPA has promulgated standards and guidelines for the control of air emissions from municipal solid waste (MSW) landfills. This Clean Air Act regulation will result in the control of up to 7 Tg/year of methane (CH_4). Collection and disposal of waste CH_4 , a significant contributor to the greenhouse effect, would result from the emission regulations. This EPA action provides an opportunity for energy recovery from the waste CH_4 that could further benefit the environment. Energy produced from landfill gas (LFG) could offset both the use of foreign oil, and air emissions affecting global warming, acid rain, and other health and environmental issues.

Results of a four-phase program showed that energy could be recovered from LFG using a commercial phosphoric acid fuel cell. Phase I, a conceptual design and

evaluation study, addressed problems associated with LFG as the feedstock for fuel cell operation. Phase II included construction and testing of the LFG pretreatment module to be used in the demonstration. Its objective was to determine the effectiveness of the pretreatment system design to remove critical fuel cell catalyst poisons such as sulfur and halides. Phase III was a demonstration of the complete fuel cell energy recovery concept. Phase IV provided guidelines and recommendations describing how the PC25™C power plant could be modified to achieve full-rated power of 200 kW on LFG, based on experience gained testing the PC25A Model.

Phase I

U. S. MSW landfills were evaluated to determine the potential power output which could be derived using a commercial 200 kW fuel cell. Each fuel cell would consume 2800 SCMD of LFG to generate 200 kW, assuming a heating value of 4.45 kcal/liter.

The potential power generation market available for fuel cell energy recovery was evaluated using an EPA estimate of CH₄ emissions in the year 1992. An estimated 4370 MW of power could be generated

from the 7480 existing and closed sites identified. The largest number of potential sites >200 kW occur in the 400 to 1000 kW range. This segment represents a market of 1700 sites or 1010 MW.

The Phase I assessment concluded that these sites are ideally suited to the fuel cell concept. The concept can provide a generating capacity tailored to the site because of the modular nature of the commercial fuel cell. The best competing options, Rankine and Brayton Cycles, are not as effective at these power ratings due to high emission and poor energy utilization.

As a result of the assessment, the conceptual design of the commercial concept was required to be modular (transportable from site to site) and sized to have the broadest impact on the market. The design is based on providing a modular, packaged, energy conversion system which can operate on LFGs with the wide range of compositions typically found in the U.S. The complete system incorporates the LFG collection system, a fuel gas pretreatment system, and a fuel cell energy conversion system. In the fuel gas pretreatment section, the raw landfill gas is treated to remove contaminants to a level suitable for the fuel cell energy con-

version system. The fuel cell energy conversion system converts the treated gas to electricity and useful heat.

LFG is utilized in 110 MSW landfills in the U.S. These systems have proven the effectiveness of LFG collection systems. Therefore, design and evaluation studies in Phase I were focused on the energy conversion concept utilizing fuel cells.

The commercial LFG-to-energy conversion system is shown in Figure 1. The fuel pretreatment system has provisions for handling a wide range of gas contaminants. Multiple pretreatment modules can be used to accommodate a wide range of landfill sizes. The wells and collection system collect the raw LFG and deliver it at approximately ambient pressure to the gas pretreatment system. In the gas pretreatment system, the gas is treated to remove non-methane organic compounds including trace constituents which contain halogen and sulfur compounds.

The commercial energy conversion system shown in Figure 1 consists of four fuel cell power plants. These power plants are designed to provide 200 kW output when operating on LFG with a heating value of 4.45 kcal/liter and for accommodating higher contaminant concentrations. The output from the fuel cell is utility grade

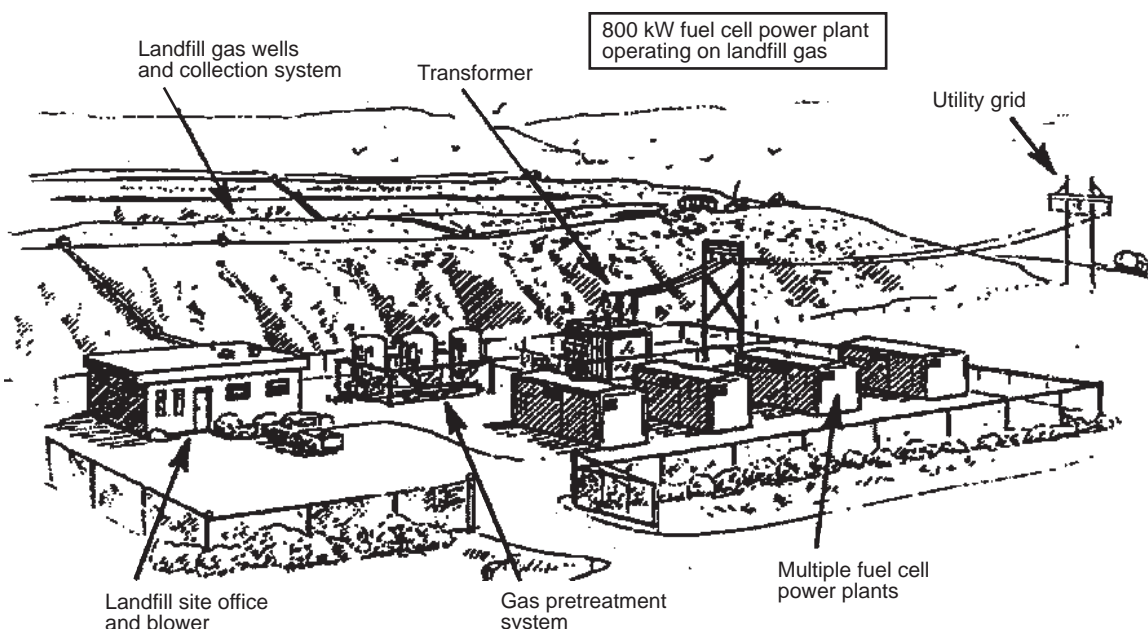


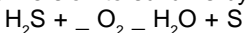
Figure 1. Fuel cell energy conversion system commercial concept.

alternating current. It can be transformed and put into the electric grid, used directly at nearby facilities, or used at the landfill itself. The power plants are capable of recovering cogeneration heat for nearby use or rejecting it to the air.

Phase II

The major element of Phase II was the construction and subsequent testing of a gas cleanup system at the Penrose Landfill site in Los Angeles (Sun Valley), California. Landfill gases consist primarily of carbon dioxide (CO₂), methane (CH₄), and nitrogen (N₂), plus trace amounts of hydrogen sulfide (H₂S), organic sulfur, organic halides, and non-methane hydrocarbons. The specific contaminants in the landfill gas of concern to the fuel cell are sulfur and halides. Both of these ingredients can "poison" and therefore reduce the life of the fuel cell power plant's fuel processor. The fuel processor converts CH₄ in the LFG stream into hydrogen (H₂) and CO₂ in an endothermic reaction over a catalyst bed. The catalyst in this bed can react with the halides and sulfides and lose its activity; i.e., poison irreversibly. The system designed to remove fuel cell contaminants is shown in Figure 2. This system is known as the Gas Pretreatment Unit (GPU). H₂S is first removed by adsorption on a packed bed. The material which performs this function is a specially treated carbon activated to cata-

lyze the conversion of H₂S into elemental sulfur which is deposited on the bed. This conversion to sulfur is by the reaction:



This bed is not regenerable on site, but the carbon can be regenerated off site if desired.

The first stage cooler removes water, some heavy hydrocarbons, and sulfides which are discharged as condensate to the Penrose plant's existing water condensate pretreatment system. Since the demonstration landfill GPU operates on a small slipstream from the Penrose site compressor and gas cooler, some of the water and heavy hydrocarbon species are removed prior to the GPU. Most of the contaminant halogen and sulfur species are lighter and remain in the LFG to be treated in the gas pretreatment unit. All remaining water in the LFG, as well as some sulfur and halogen compounds, are removed in a regenerable dryer bed which has a high capacity for adsorbing the remaining water vapor in the LFG. There are two dryer beds so that one is always operational while the other is being regenerated. The dry LFG is then fed to the second stage cooler. This cooler can be operated as low as -32° C and potentially can condense out additional hydrocarbons if present at high enough concentrations. In addition, the second stage cooler reduces the temperature of the carbon bed, therefore enhancing its adsorption perfor-

mance. The downstream hydrocarbon adsorption unit, whose temperature is controlled by the second stage cooler, is conservatively sized to remove all heavy hydrocarbon, sulfur, and halogen contaminant species in the LFG. This unit consists of two beds of activated carbon so that one is always operational while the other is being regenerated. Both the regenerable dryer and hydrocarbon removal beds operate on a nominal 16 hour cycle of each set of beds operating in the adsorption mode for 8 hours and regeneration mode for 8 hours. The gas then passes through a particulate filter and is warmed indirectly by an ambient-air finned-tube heat exchanger to ensure a fuel inlet temperature above 0° C before being fed to the fuel cell unit.

The GPU was constructed at International Fuel Cells Corp.'s facility in South Windsor, Connecticut. Construction of the unit was completed in February 1993. Upon completion of construction, the unit was evaluated at the South Windsor facility, using N₂ as the test gas. The unit successfully completed the 16 hour control test verifying that rated flows, pressure, and temperature were achieved. After the test, the unit was shipped to the landfill site located in Los Angeles, California, where it was installed in April 1993.

The GPU was successfully tested at the Penrose landfill site in Los Angeles (Sun Valley), California. The GPU suc-

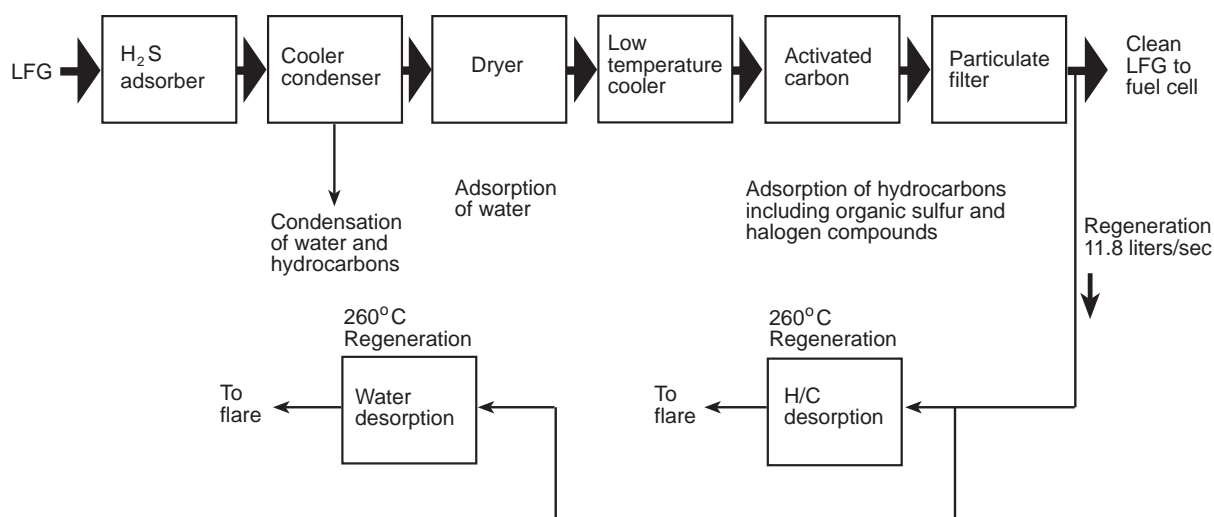


Figure 2. Landfill gas pretreatment unit (GPU) system.

cessfully removed the sulfur and halogen compounds contained in the LFG to a level significantly below the specified value for use with the phosphoric acid fuel cell and to date has operated for approximately 2300 hours.

Table 1 compares the measured sulfur and halide contents of the gas produced by the GPU to the specification value. The data verify that the GPU reduces the sulfur and halide contents of LFG to a concentration lower than required by the fuel cell power plant. The exceptionally low GPU exit contaminant levels indicate that the low temperature cooler is not essential, even though the reduced temperature in the activated carbon bed increases capacity for sulfur and halogen compounds. For system simplification in the future, it may be beneficial to eliminate the low temperature cooler, and simplify the refrigeration system, in exchange for increasing the activated carbon bed volume slightly. The favorable results of the GPU testing led into Phase III, which entailed characterizing the performance (i.e., emissions, efficiency, and power output) of the commercial phosphoric acid fuel cell power plant when operating on LFG which has been purified by the GPU.

Phases III and IV

The power plant utilized in this program is a commercial PC25™ 200 kW phosphoric acid fuel cell. The power plant was shipped and installed at the Penrose Landfill during 1994. The unit was started on natural gas prior to its modification for operation on LFG. This testing was conducted to establish a baseline performance level. Upon completion of the natural gas testing, the unit was shut down, modified for LHV gas, and subsequently connected to the GPU for testing on LFG. All power produced by the unit was fed into the electrical grid for sale to the local electrical utility, the Los Angeles Department of Water and Power (LADWP). This fuel cell is the first ever connected to the LADWP utility system grid. The revenue produced by the sale of this electricity was used to help offset program costs.

Emission testing of the power plant effluent was conducted during February 1995. Using EPA methods 6c, 7e, and 10, respectively, emission levels of sulfur dioxide were undetectable at a detection limit of 0.23 ppm, while nitrogen oxides averaged 0.12 ppm and carbon monoxide averaged 0.77 ppm. All the data are dry measurements corrected to 15% oxygen.

These emission levels verify that fuel cells can operate on LFG while maintaining the low emission levels characteristic of this commercial fuel cell power plant.

An exciting dimension of the PC25 operating on LFG is that, unlike internal combustion engines and turbines, the unit has significant siting characteristics due to its demonstrated low levels of emissions, noise, and vibration. It can be located remote from the landfill using gas piped from the site. In this way, its thermal energy, as well as its power, can be put to constructive use at a customer's building. In addition, by siting at the building, the economics improve significantly since the power plant displaces commercial electricity which has a much higher cost than the revenue which would be received if the fuel cell were sited at a landfill and received utilities' "avoided" cost. Utilizing the fuel cell's thermal energy can result in an overall efficiency [i.e., (Electrical Energy plus Thermal Energy)/Energy Content of Gas Consumed] of 80%. This high efficiency conserves natural resources and reduces the amount of CO₂ emitted to the atmosphere. It also improves the economics, since heat may be sold to the building owner.

Table 1. GPU Sulfur and Halide Contaminant Removal Performance and Specification (ppmV)

Contaminant	Inlet	Outlet	Specification
Total Sulfur (as H ₂ S) ^a	117	≤0.047	≤3
Total Halides (as Chloride) ^b	47	≤0.032	≤3

^aMeasured by gas chromatography/flame photometric delineation by EPA methods 15, 16, and 18

^bMeasured by gas chromatography by EPA method TO-14

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Ronald J. Spiegel is the EPA Project Officer (see below).

The complete report consists of two volumes, entitled "Demonstration of Fuel Cells to recover Energy from Landfill Gas—Phase III. Demonstration Tests, and Phase IV. Guidelines and Recommendations:"

Volume 1. Technical Report (Order No. PB98-127368; Cost: \$25.00)

Volume 2. Appendices (Order No. PB98-127376; Cost: \$57.00)

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